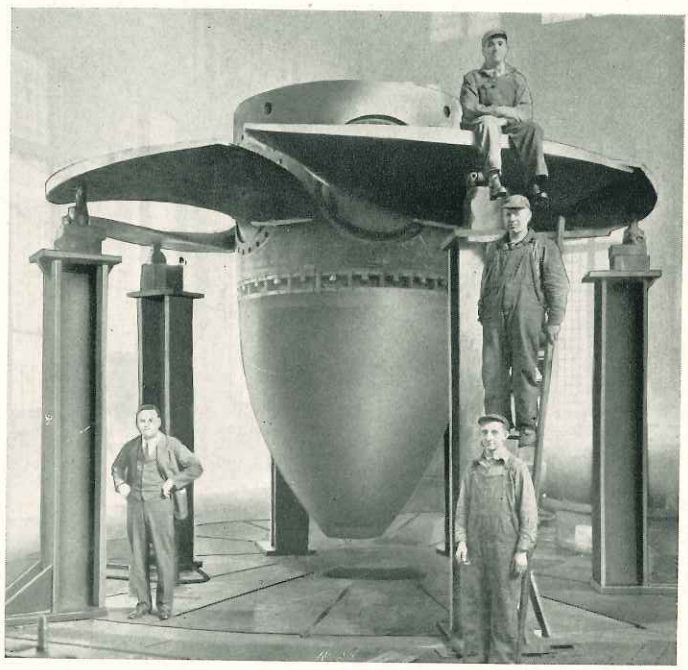
Highest-Powered Kaplan Turbines Installed at Safe Harbor



Smith-Kaplan Adjustable Blade Runner

Bulletin No. 128

DIVISION 9 PAPER NO.
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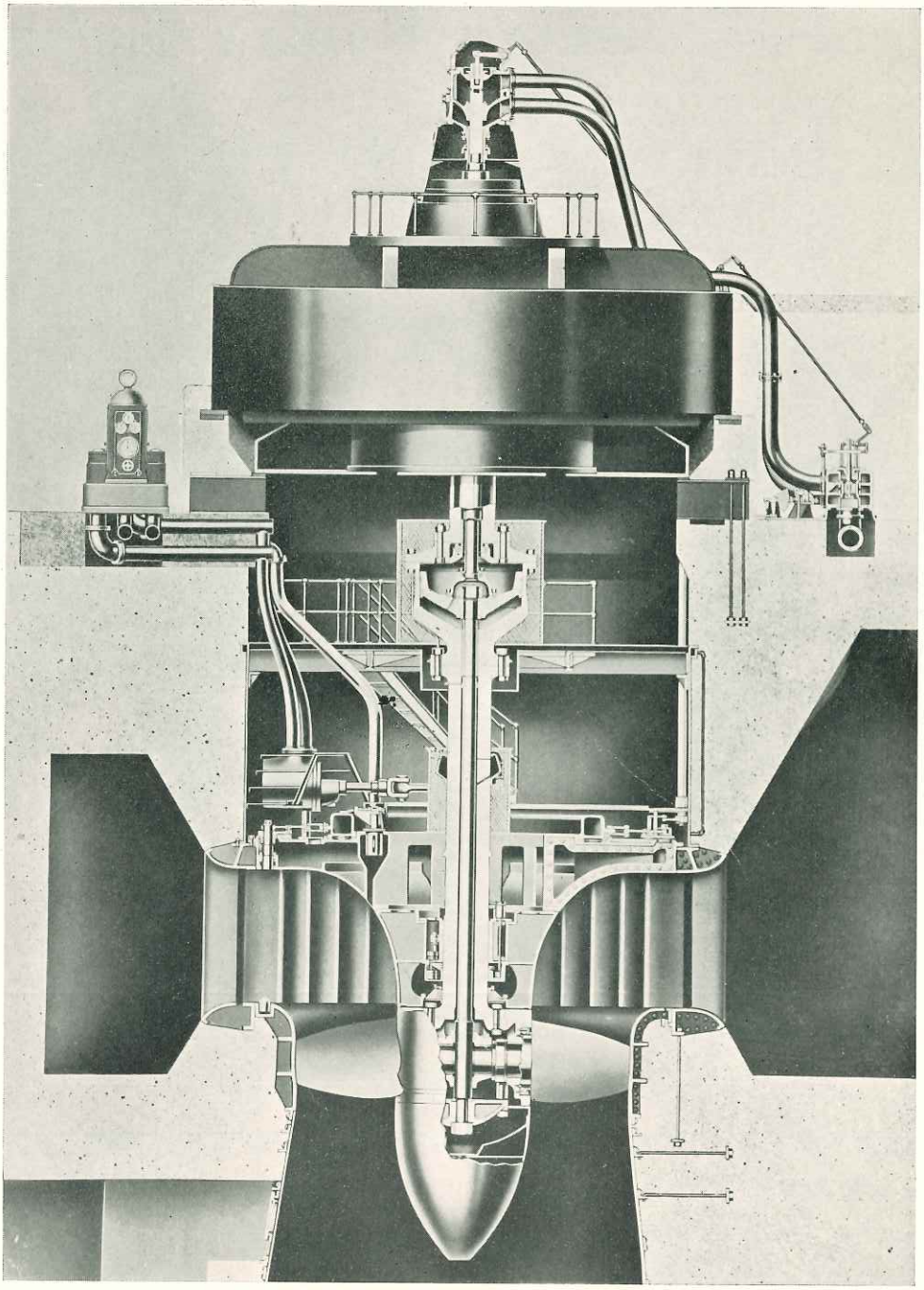
Power, March 15, 1932

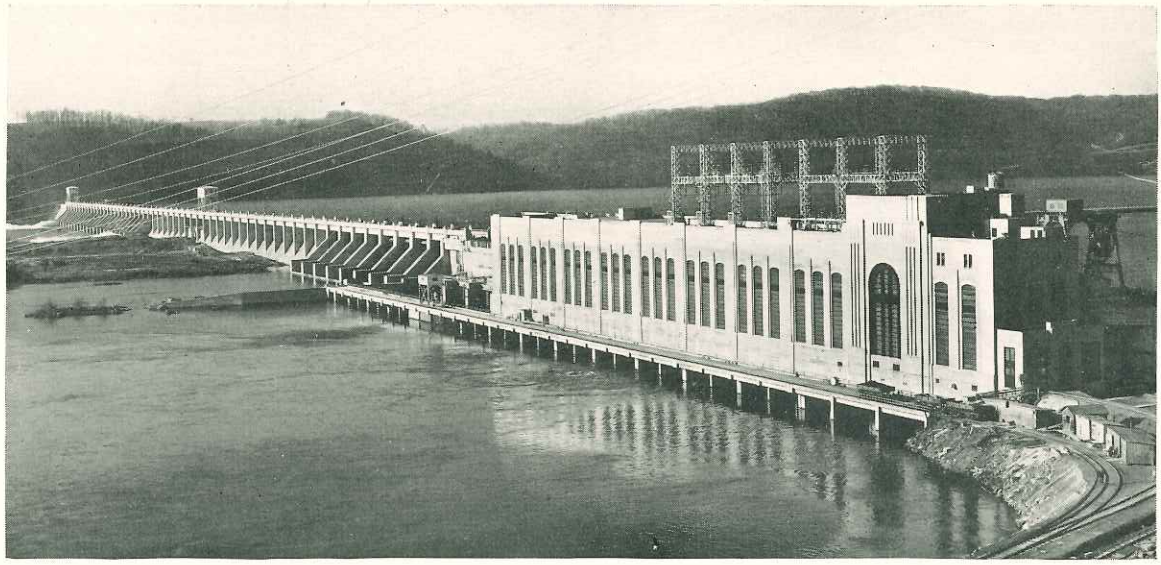
S. MORGAN SMITH CO.
YORK, PA.

SMITH-KAPLAN ADJUSTABLE BLADE TURBINES



The above view shows a general cross section thru one of the main units now being installed at the Safe Harbor Water Power Corporation development on the Susquehanna River. Each unit consists of a vertical shaft, governor controlled, adjustable blade Kaplan turbine direct connected to an electric generator. The turbines will each develop 42,500 H.P. at 109.1 R.P.M. under an effective head of 55 ft. Exhaustive model tests of the complete setting were made to determine the most efficient form for the concrete spiral casing and draft tube and also for the proper setting to eliminate all danger of cavitation.

S. MORGAN SMITH CO. — YORK, PA.



Safe Harbor power house and dam comprise a structure 4,865 ft. long

Highest-Powered Kaplan Turbines Installed at Safe Harbor

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Safe-Harbor hydro-electric plant of the Safe Harbor Water Power Corporation will have an initial installation of six 42,500-hp. automatically adjusted-blade propeller-type turbines to operate under a 55-ft. head. Provisions are made in the design for six additional units making the ultimate capacity 510,000 hp. These are the highest-powered units of their type in the world and have a discharge of approximately 9,000 sec.-ft. at full load

FEW RIVERS in the United States have hydro-electric plants installed comparable with those on the Susquehanna in Pennsylvania and Maryland. On this river, between Columbia, Pa., and tidewater, there is a fall of about 225 ft. Practically all of this head is utilized in three great plants, which, when built to their ultimate capacity, will have an aggregate installation of over 1,250,000 horsepower.

Near tidewater, in Maryland, is Conowingo plant of the Susquehanna Power Co., with an installed capacity of seven 54,000-hp. units and space for four additional machines. This plant operates in parallel with the Philadelphia Electric Co.'s system. Fifteen miles above Conowingo is the Holtwood plant of the Pennsylvania Water & Power Co. It has been built to its ultimate capacity of 158,000 hp. and connects to the power systems of Baltimore, Md., and Lancaster, York and Coatesville, Pa.

At Safe Harbor, eight miles above Holtwood, the Safe Harbor Water Power Corporation, owned jointly by the Pennsylvania Water & Power Co., and the Consolidated Gas Electric Light and Power Company, Baltimore, Md. is rapidly completing a 255,000-hp. initial installation of what will be ultimately a 510,000-hp. development. This plant will eventually operate under a 55-ft. head, will back the water up to Columbia, and will connect to the same systems as the Holtwood plant.

All three plants are designed for run-of-river operation, and have sufficient storage to make them well adapted to peak-load service. They are normally operated on base load during high water, and carry the peak loads during low water.

At the site of the Safe-Harbor development there is an island in the center of the river. Beginning at the west side of the river there is a bulkhead section of the dam 482 ft. long. Between this and the island bulkhead is a 1,356-ft. spillway with 24 Stoney gates, each with a clear span 48 ft. long and providing for 32 ft. of water over their sill. Across the island a 1,356-ft. bulkhead section of the dam is constructed to which the east spillway section, 454 ft. long, connects. In this spillway there are four Stoney gates and four double-leaf gates, the latter for regulating flow. A 58-ft. bulkhead section connects the east spillway with the power house section 916 ft. long. Between the power house and the east bank of the river is a 243-ft. bulkhead The dam and powerhouse form a structure 4,865 ft. long.

With the exception that the upper leaf of each of the

four regulating gates, which are lowered by remotely controlled motor-driven hoists located in the tunnel inside the dam, the gates may be raised or lowered by either of two 150-ton gantry cranes. The upper leaf of the four regulating gates can be raised or lowered from the switchboard in the power house. This latter arrangement gives the switchboard operator control of regulating the pool level during normal flow, and serves as a fine adjustment when the larger gates are open. By this means the number of main-gate operations may be materially reduced.

A skimmer wall of structural-steel framing encased in concrete extends upstream from the west end of the power house, parallel with the river, for 1,400 ft. At its upper end the wall is connected to the shore by a rock-filled dyke forming a forebay for the plant. It is expected that this skimmer wall and dyke will keep the forebay free of floating ice and debris.

The power-house concrete substructure is built as part of the dam, and is designed for an initial installation of seven main units and two house-service units, forming a structure 610 ft. long. Intakes for five future units have been constructed in the dam, and provisions made so that draft tubes for them may be built at relatively low cost when additional capacity is required.

There are three intakes to each unit, which are protected by racks having bars spaced on 6-in. centers. The bars in these racks are stream-lined in cross-section so so that they offer a minimum resistance to the flow. A comparison of the costs of stream-line and rectangular bars showed that the former did not add materially to the investment for racks.

In the center intake of the three to each wheel is a gate with fixed rollers and a screw hoist. The other two intakes are equipped with plain slide gates that are lifted by one of the two gantry cranes on the intake deck. The filling of the penstocks and the final closing off of the water are done with the center gate operated by the screw hoist.

An outstanding feature of the plant is the propeller-type wheels with blades adjusted automatically as the load changes, to maintain high efficiency over a wide range of load. The relation between blade angle and gate opening can be varied manually to compensate for changes in head. When selecting the turbines four types of propeller runners were considered. These included the conventional fixed-blade type; manually adjusted-blade type, requiring shutting the unit down to make the adjustment; manually adjusted-blade type, adjustment being made while the unit is in operation; automatic adjustable-blade, Kaplan type, the pitch of the blade being controlled by the speed governor. Frances-type units were also considered, but because of their larger space requirements and loss of capacity under reduced head during flood conditions, they were not suited to existing conditions.

Propeller-type runners with manually adjusted blades with the units at rest were also considered unsuited to the expected load and head conditions. The difference in cost between units having manually adjusted blades when in operation, and those having automatically adjusted blades was not sufficient to warrant considering the former. This reduced the choice to either the fixed-blade type, automatically adjusted-blade type, or a combination of the two.

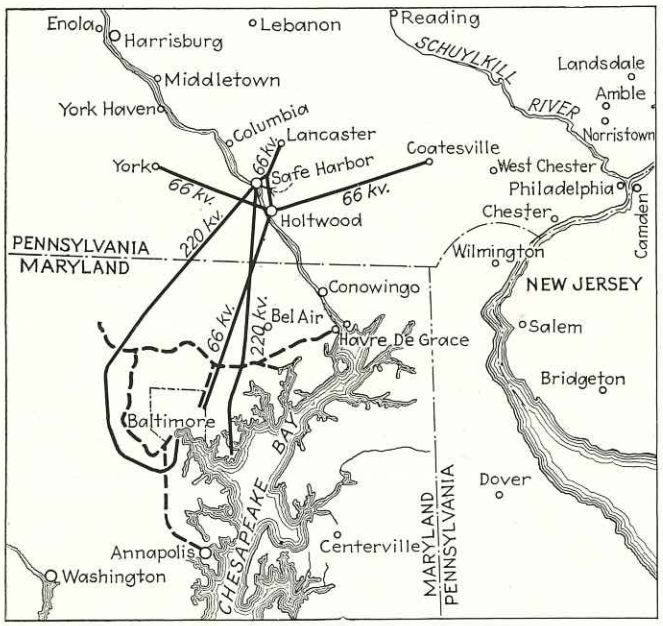


Fig. 1—Transmission lines connect Holtwood and Safe-Harbor plants with Baltimore, Md. and York, Lancaster and Coatesville, Pa.

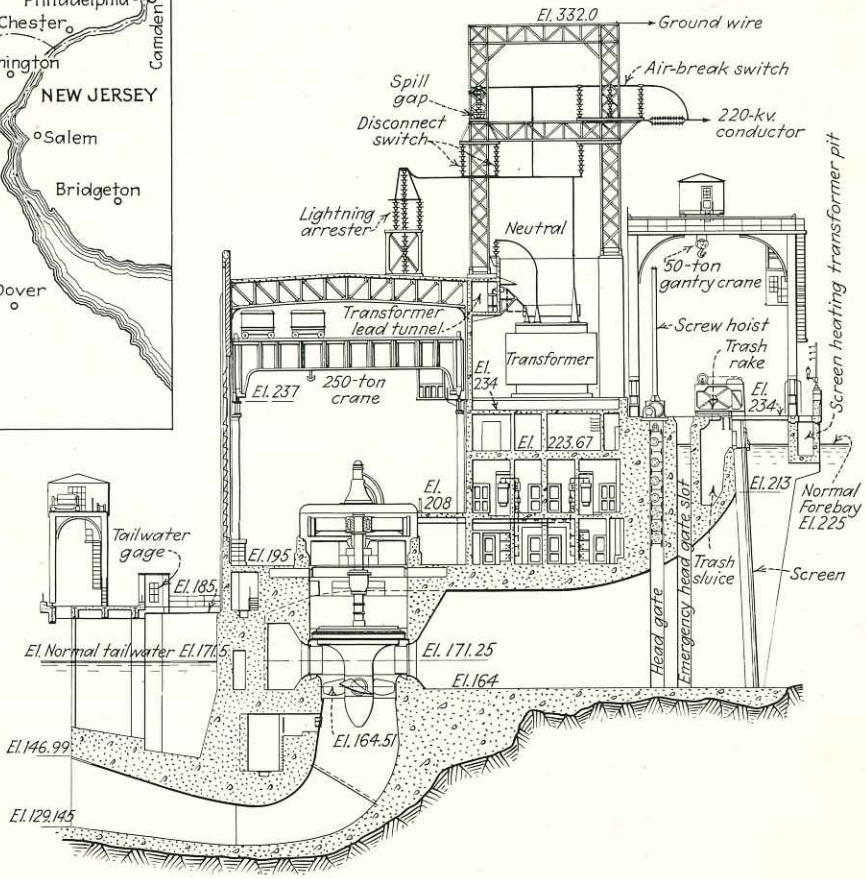


Fig. 2—The turbine runners are set with their center lines 7 ft. below normal tailwater level to prevent cavitation. This location was determined by tests on models in the hydraulic laboratory of the Pennsylvania Water & Power Company at Holtwood

It was found that the high sustained efficiency of adjustable-blade type units over wide ranges of load, and their higher output under reduced head during flood conditions, offset their 15 or 20 per cent higher cost over the fixed-blade type. A combination of automatically adjusted-blade and fixed-blade types would have met the conditions existing at the time the plant was designed, but it was evident that these conditions might not continue, and that it might be desirable to operate the plant in sections to meet future load requrements. These considerations, and the advantages of complete uniformity of design, led to selecting all Kaplan-type wheels.

The initial installation will include six 42,500-hp., 109.1-r.p.m. units. Four of these have been put into operation, and the other two will be installed during the next two years. Two house turbines of the francis type, rated at 3,100 hp. at 180 r.p.m., under a 55-hp. head, have also been installed. These Kaplan turbines are the highest powered in the world, have runners 18 ft. 4 in. in diameter, and will discharge about 9,000 sec.ft. at full gate and normal head. Their runners are set with their centerline 7 ft. below normal tailwater level, to prevent cavitation. This location of the runners with relation to tailwater elevation was determined by exhaustive model tests in the hydraulic laboratory of the Pennsylvania Water & Power Co. at the Holtwood plant.

Because the runners are below tailwater, special provision had to be made for unwatering the wheel casing. Two means of doing this have been made available. Two units are so equipped that the tailwater can be lowered automatically by admitting compressed air to the wheel's casing. As the gates on these units approach the no-load position the air valve can be made to begin to open and admit compressed air to the wheel casing. If the gates are closed, as during running-reserve or synchronous condenser operation, air pressure will be maintained automatically in the wheel casing that will keep the water level below the runner.

An alternative method of unwatering the wheels when there is work to be done is to put stop logs in the discharge end of the draft tube and pump out the water. Two movable unwatering pumps on special bedplates are provided. These are located in the unwatering tunnel and can be transported on an overhead monorail hoist to the unit where they are needed. The pumps can be anchored to slots in the concrete floor of the tunnel and connected to the draft tube by a special adapter fitting.

A great deal of study was given to the design of the governing system for the main units. On these machines the governor has to perform the double function of regulating speed and adjusting the pitch of the runner's blades. To provide for this the governor pressure tanks have about double the capacity of those for fixed-blade turbines. The units are arranged in pairs as related to the governing system. Each unit of a pair is provided with its own governor, oil pump, twin pressure tanks but with a sump tank comon to both units. The governor oil pumps, the actuators and the pressure tanks are on the operating-floor level. Below the operating floor is the sump tank, having two compartments. The two oil-pressure pumps, the four pressure tanks and the compartments of the sump tank are inter-connected so that either half or the system or both may be used. One pump and twin pressure tank has sufficient capacity to take care of two units. Normally, one pump will serve two units, but should it fail for any reason, the second

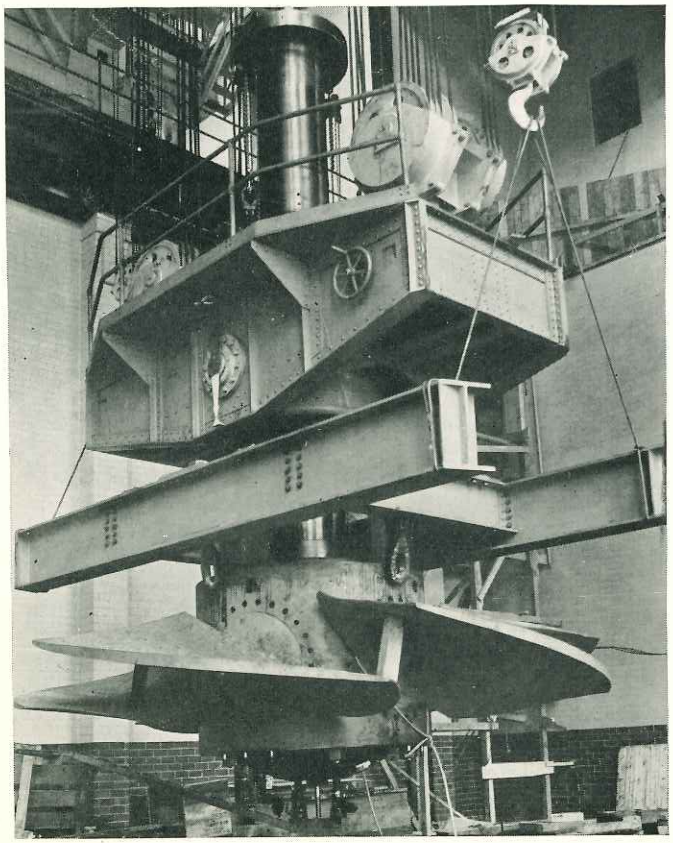


Fig. 3—One of the turbine runners supported in a special lifting equipment so that it can be handled by a crane

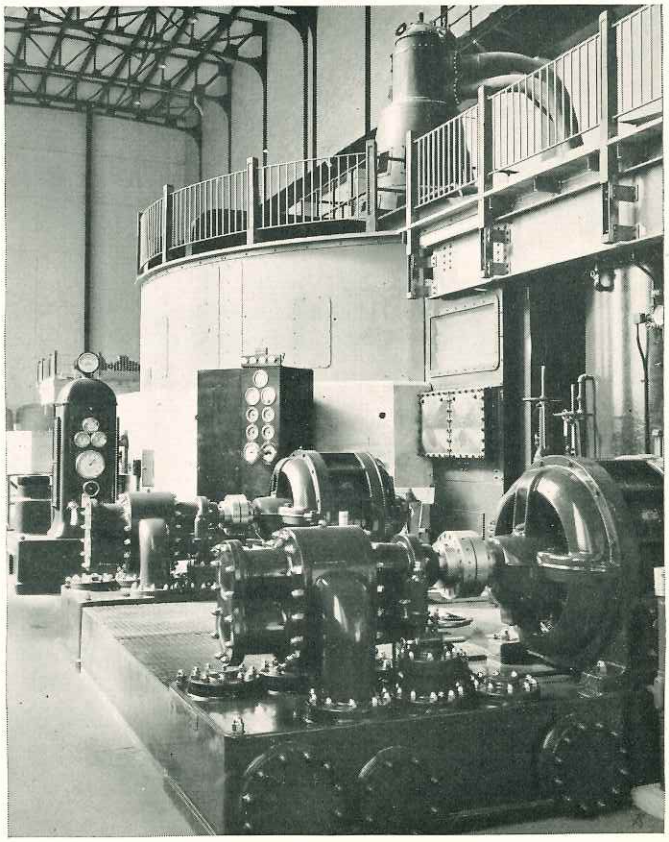


Fig. 4—The anchor bolts that hold the governor oil pumps to their base plate also connect them to the oil pipes

pump will be started automatically by a pressure switch. This arrangement is a combination of the unit and central governor oil-pressure systems.

A special feature of the oil-pressure pumps is the absence of external piping, Fig. 4, since the anchor bolts that hold the pumps to their base plates also connect them to the suction and discharge oil pipes. The pumping units were designed especially for quick replacement of either pump or motor, and they are located in the power house so that they may be served by the main power-house cranes.

Referring to Fig. 5, the governing system for a unit consists of the actuator *A* that serves the dual purpose of speed regulation and to adjust the pitch of the runners blades. The valves for the speed-governing mechanism are located at the actuator and the servomotors are on top of the turbine's crown plate, as is usual practice. For the blade-adjusting mechanism, the control valves are located on the operating floor at *B*, Fig. 5, and the servomotor is in the coupling at *C*, between the turbine and generator. The control valves and servomotor are connected by two concentric pipes, the inner of which can be displaced vertically to serve as a restoring rod, running down the center of the generator shaft. A shaft runs from the piston of the servomotor to the blade-adjusting mechanism in the hub of the runner. The runner's hub contains 1,100 gal. of oil, a sufficient head of oil being maintained to prevent water from leaking into the hub.

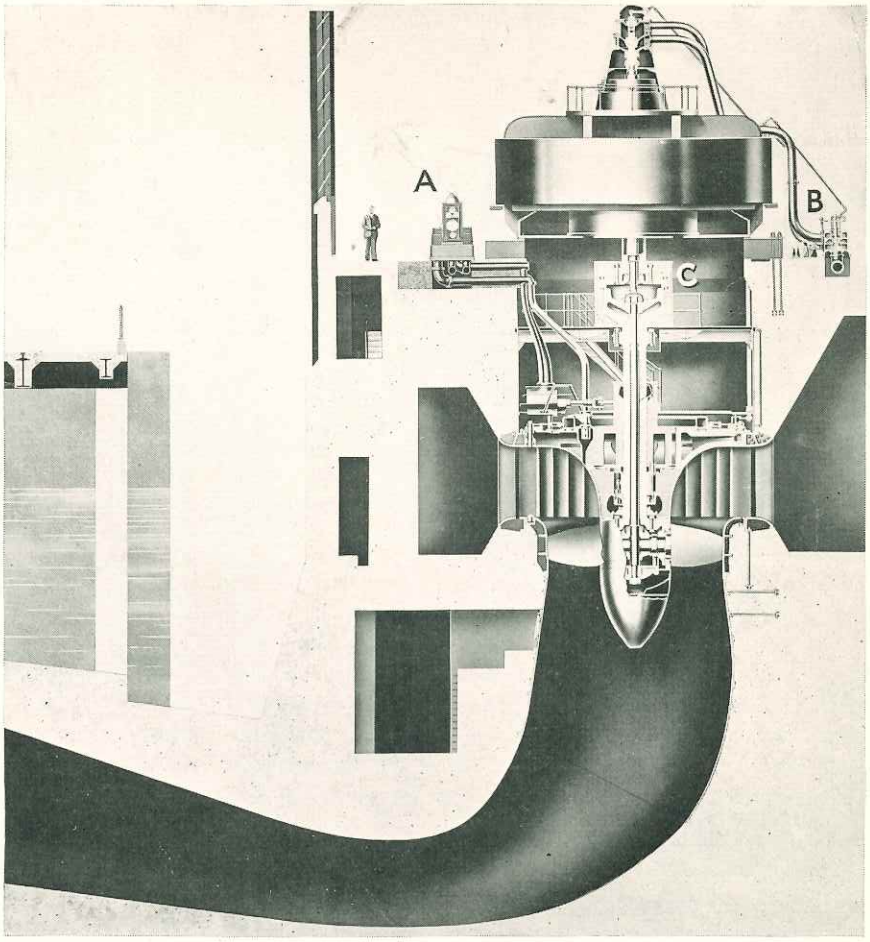


Fig. 5—The valves B and servomotor C adjust the angle of the runner blades to maintain high efficiency over a wide range of load

From the foregoing it is evident that the system for regulating the pitch of the turbine blades is similar to that for controlling the gates' position. The two work in synchronism, in response to the actuator on load changes. To compensate for the effects of change in head on the efficiency and power of the unit, the blade-adjusting valves are provided with a set of cams for altering the gate-blade relation. Normally, the units will operate under a fairly constant head, adjustment for changes in head being required at infrequent intervals only.

In the governor's operation and control of the machine there are some interesting features. Once a unit is started from rest the gates will not open above speed-no-load position until the actuator is energized by three-phase voltage. On the pilot exciter there are three slip rings to supply 162-volt, 7.27-cycle power to the actuator motor and the torque motor on the safety latch. Until the torque motor is energized with three-phase voltage, the pilot valve cannot rise beyond speed-no-load position, except when raised manually by a special knob which cannot be left in raised position. This is to prevent the unit from being placed in service under governor control without the flyballs turning. After the unit has started and three-phase voltage is on the actuator, failure of one phase will not shut the unit down, since the actuator motor will operate single phase and act as a phase converter to supply three-phase voltage to the torque motor to hold the safety latch in the released position.

The inherent speed drop can be adjusted to any desired relation between gate opening and speed by changing the position of a follower along a radial cam between the restoring mechanism and the speeder spring. Provision is also made so that if the relation between gate opening and power output should prove to be so distorted that at one part of the curve the power increases rapidly for a small change in gate opening, a special cam can be designed and substituted so that a straight-line relation between speed and gate movement can be obtained. This would prevent the unit from being oversensitive on one part of the governor stroke, and sluggish on another. The relation between machines when operating in parallel would then be stabilized, which is a highly desirable feature.

There is a definite load limit that can be applied to the machines without causing cavitation on the runners. Because of variations in head, due to flow changes in the river, the load limits will change on the machines. For example, as tailwater elevation increases, as during flood periods, the allowable gate opening may be increased without exceeding the cavitation limit. Provision is made so that equipment can be installed for setting of the load limit from the switchboard by the operator. The gate-position, load-limit position, tailwater and forebay levels are all indicated at the switchboard. The operator

will be provided with a set of curves showing the relation between load limit and cavitation for different head conditions, and it will be up to him to see that the machines are not loaded beyond the proper limit.

On the four units now installed, Nos. 3, 4, 5 and 6, the generators are three-phase, 60-cycle, 13,800-volt machines, normally rated at 28,000 kw., 0.9 power factor. Sufficient field and excitation capacity are provided to operate the generators at 31,111 kva. at 0.8 power factor and 60 deg. C. rise. The generators are designed mechanically for 36,000 kw. at unity power factor, and will have a maximum electrical rating of 36,000 kva. at 0.8 power factor and 80 deg. rise. These generators are of the overhung-rotor type with the Kingsbury thrust bearing and single segmental-shoe guide bearing combined in a housing below the rotor.

Generator No. 2, originally planned for three-phase, 60-cycle, will be built for single-phase 25-cycle operation. It will have a rating of 28,000 kw. at 0.8 power factor and 107.1 r.p.m. and will supply power to the Pennsylvania Railroad electrification between Perryville, Md. and Washington. A 300-r.p.m. outdoor frequency-changer set, rated at 25,000 kw., 0.8 power factor, will also be installed at the plant to convert three-phase, 60-cycle, power to 25-cycle single-phase for railroad load. The power house superstructure has been completed for seven units. No. 1 position is being reserved for a second single-phase 25-cycle unit, the speed-ring for which is now in place.

PRINCIPAL EQUIPMENT

Main turbines, 3	S. Morgan Smith Co.
Main turbines, 3	I. P. Morris Division—Baldwin-Southwark Corp.
House turbines, 2	S. Morgan Smith Co.
Governors	Woodward Governor Co.
Main generators, 4	General Electric Co.
Main generators, 2 House generators, 2	Westinghouse Elec. & Mfg. Co.
Thrust bearings	Kingsbury Machine Works
CO_2 fire-protection systems	Walter Kidde & Co.
Oil-treating equipment	De Laval Separator Co.
Storage batteries	Electric Storage Battery Co.
Main 250-kv. transformers	General Electric Co.
Main 66-kv. transformers	Westinghouse Elec. & Mfg. Co.
House transformers	American Brown Boveri (Allis-Chalmers Mfg. Co.)
13-kv. oil circuit breakers	Westinghouse Elec. & Mfg. Co.
13-kv. disconnecting switches and bus supports	Electric Power Equipment Corp.
480-volt air circuit-breaker switchboard (totally enclosed truck type)	I-T-E Circuit Breaker Co.
Main switchboard	Westinghouse Elec. & Mfg. Co.
Auxiliary switchboards	Westinghouse Elec. & Mfg. Co. Pringle Electrical Mfg. Co. Trumbull Electric Mfg. Co.
High tension (230-kv. and 69-kv.) disconnecting and air break switches	Railway & Ind. Eng. Co.
Flood gates and double-leaf gates	Newport News Shipbuilding and Drydock Co.
Double-leaf gate hoists	Bartlett-Hayward Co.
Head gates	M. H. Treadwell Co.
Head-gate hoists	Hardie-Tynes Co.
Spillway gantry cranes	Whiting Corp.
Intake gantry cranes	Morgan Engineering Co.
Power house cranes	Harnischfeger Corp.
Transformer crane	Morgan Engineering Co.
Draft-tube stop-log crane	Alliance Machine Co.
Heating boilers	Babcock & Wilcox Co.

Excitation for each main generator is supplied from a direct-connected main exciter and a pilot exciter. As already mentioned, the pilot exciter has three rings from which power is supplied to the flyball motor on the actuator. There is a motor-driven spare exciter that may be connected to any one of the main generators if the direct connected exciter fails.

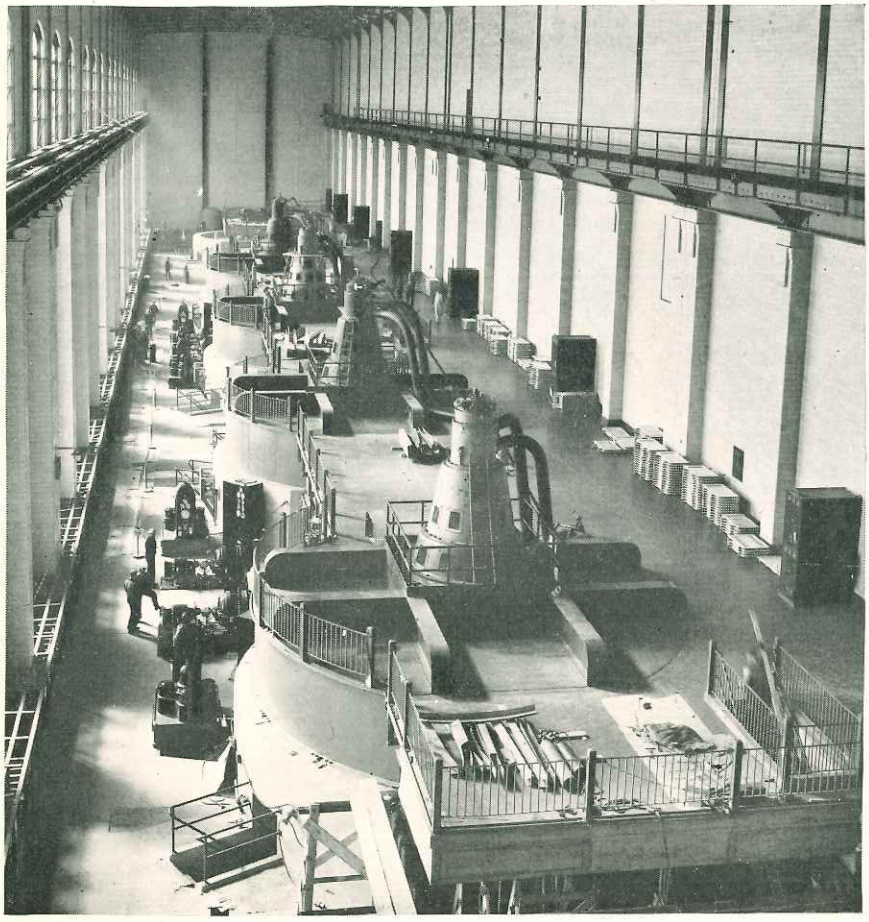
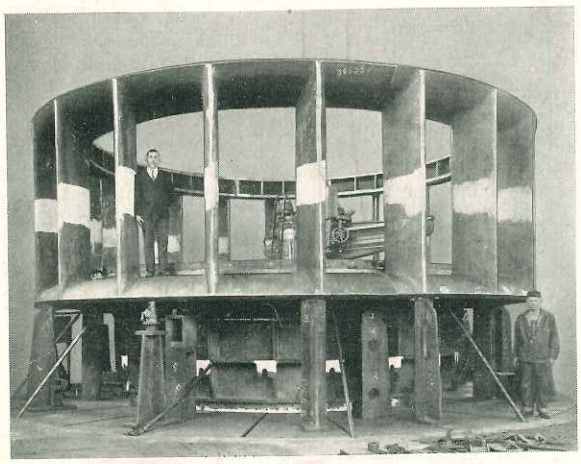


Fig. 6—Four main units normally rated at 28,000 kw., 0.9 power factor are now installed with space in the present power house for three more

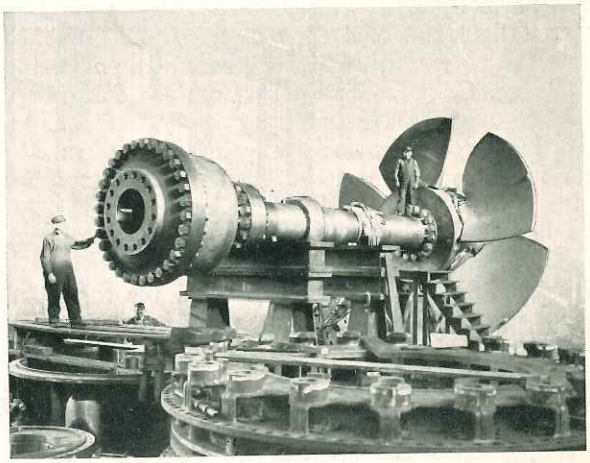
The construction work on the project was carried forward with unusual efficiency profiting by many favorable circumstances, and the plant went into operation several months ahead of schedule. Federal and State permits were obtained in April, 1930, to start cofferdam work in the river, and the first unit in the plant was started in December, 1931, one year and eight months after starting work in the river. Some idea of work involved is found in the fact that the construction included 1,700,000 cu.yd. of rock and earth excavation, mostly rock, and placing 490,000 cu.yd. of concrete in a structure nearly one mile long.

All the design work was handled by the engineers of the Pennsylvania Water & Power Co., as was the model testing of the unit in the laboratory at the Holtwood plant. All construction work was done by the Arundel Corporation of Baltimore while the installation of the electrical and mechanical equipment in the power house was handled by the power company's engineering and construction department.

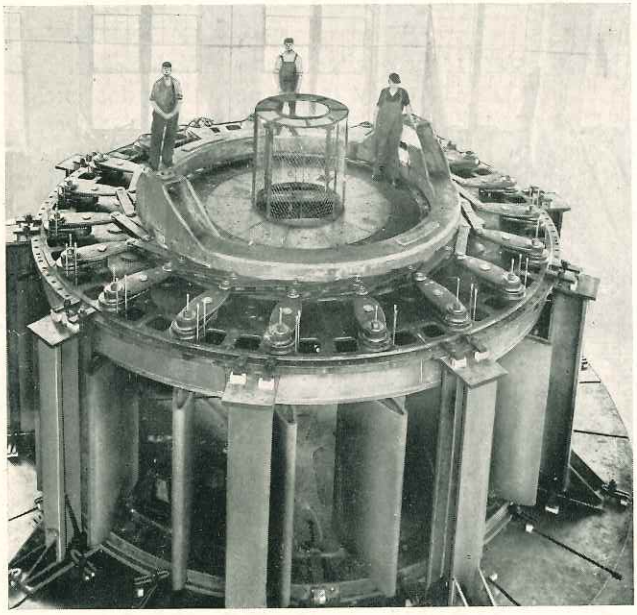
Shop Views of Smith-Kaplan Turbine Equipment for Safe Harbor



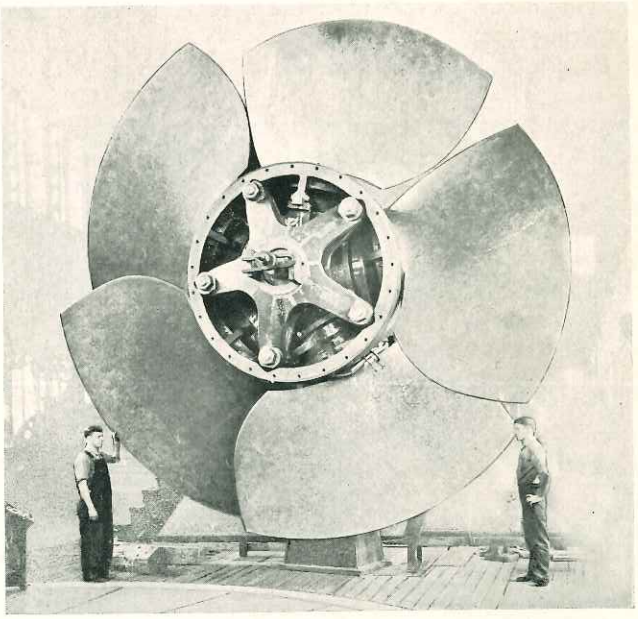
Speed Ring and Bottom Plate assembly. A comparison with the two men gives some idea of the size of the equipment.



Assembly of the Smith-Kaplan automatically adjustable blade runner with the shaft and blade operating servomotor.



View of the Wheel Case, assembled without the Speed Ring, showing the wicket gates and the gate operating mechanism on the Top Plate.



Bottom of the automatically adjustable blade Runner with the hub extension removed to show the blade operating mechanism. The Runner is over 18 feet in diameter.

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S. MORGAN SMITH CO.

Hydraulic Turbines and Accessories

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